ARMY RESEARCH LABORATORY

Improvements to the Acoustic Multistream Propagation Program

by Markku P. Kotiaho

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13. ABSTRACT *(Maximum 200 words)*

The Acoustic Multistream Propagation Program (AMPP) makes use of repeated calls to the Fast Field Program (FFP) to calculate the sound pressure level from a combination of sources and scatterers in a horizontally stratified atmosphere. Although FFP treats only isotropic sources, AMPP has been used to produce dipole type fields by coherent summation of the sound pressures of appropriately positioned sources and scatterers. In addition, scatterers can be positioned to scatter the sound pressure of the incoming field into a shadow zone, which may be useful for non-line-of-sight acoustic detection problems. The basic characteristics of AMPP have been described elsewhere. This report discusses modifications made to AMPP since April 1993, in support of, and including, the coherent summation subroutine. An example is given on how to use AMPP to model anisotropic scatterers, and graphical output from this example is included. Finally, some remarks are included regarding the limitations of AMPP.

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1. Introduction

The Army Research Laboratory (ARL) has researched acoustic techniques for non-line-of-sight detection systems for use on the battlefield. Toward this goal, many computer programs have been written to simulate acoustic propagation in the atmosphere.

The Acoustic Multistream Propagation Program (AMPP) is a computer program, written in FORTRAN, developed by ARL to extend the capabilities of the Fast Field Program (FFP). The FFP is described in an article for calculation of sound pressure levels propagated through a layered atmosphere (Raspet et al. 1985). The basic characteristics of AMPP have been described in another government report that also lists some other programs in use for similar calculations (Auvermann, Reynolds, and Brown 1995).

FFP calculates the sound pressure level from a single, isotropic source at a range of points at a specified detector height. Allowing the atmosphere to be layered parallel to the ground permits variation of relevant acoustic parameters in the vertical direction. The parameters are constant within each layer, but they can differ from one layer to the next. The ground and the boundaries between the atmospheric layers are characterized as impedance surfaces. The propagation is calculated in the forward direction only, thus, by convention, the source is placed at zero range.

AMPP makes use of FFP to calculate the sound pressure levels of multiple sources at multiple detector heights by looping through all the source-detector (SD) pairs and calling FFP for each one. Scattering from atmospheric turbules is taken into account by introducing a new kind of source. A turbule, hereafter referred to as a scatterer, is treated basically the same as a source, except that the range is not zero. Backward scattering is neglected by AMPP because FFP calculates propagation only in the forward direction.

From April 1993 to February 1995, several modifications were made to AMPP to increase its functionality. The first change fixed a bug known to exist in AMPP prior to April 1993. Subsequently, alterations were made to the code to permit coherent summation of the sound pressures from multiple sources and

scatterers. The alterations included the addition of a subroutine and several new variables. The addition of a coherent summation capability gave AMPP the ability to model anisotropic scatterers. Previous work documented a need for the coherent summation capability in acoustic propagation models (Auvermann and Goedecke 1992).

This report proceeds as follows:

- Section 2 discusses the modifications to AMPP since April 1993.

- Section 3 discusses the use of AMPP to model anisotropic scatterers. Graphical results are displayed for uniform and upward refracting atmospheric conditions.

- Section 4 summarizes this report and offers some concluding remarks.

- Appendices A and B contain additional user information.

2. Improvements to AMPP

This section documents the modifications made to AMPP from April 1993 to February 1995.

Since April 1993, several changes have been made to AMPP. It was known at that time that there was a bug in the code, which manifested itself in erroneous sound pressure level calculations for each SD pair after the first pair. Because AMPP makes a call to FFP for each SD pair, the type of bug suggested the possibility that some variables in FFP were not being reset correctly. The variable arrays C, MU, RHO, and Z that give the characteristics of each atmospheric layer were being reset in a manner that, effectively, mixed some layers and input random data into others. For example, for the third SD pair, each atmospheric layer would have the characteristics that, originally, were held by the second layer beneath it. The bottom two layers acquired random characteristics. After about 15 calls to FFP, the output bore almost no resemblance to the expected output. The problem was corrected by saving the original values of the parameters in the main portion of AMPP and resetting them according to the saved values, after each call to FFP.

A subroutine called XTRASRC, described in a government report (Auvermann, Reynolds, and Brown 1995), was to be responsible for the coherent summation of the sound fields from multiple sources and scatterers — a central feature of AMPP. However, at the beginning of the work period, there was no such subroutine — at least, not to our knowledge. Thus, the next major modification to AMPP was to write the XTRASRC subroutine and incorporate it into AMPP.

XTRASRC was first incarnated as two separate subroutines — namely, INTERP and ADDPRESS. The purpose of INTERP was to interpolate the complex sound pressures of each source or scatterer at a predetermined grid of range points, for each detector height. The interpolated values were passed to ADDPRESS. ADDPRESS saved the interpolated values, summed them, and computed the resulting (logarithmic) sound pressure level. The interpolation was necessary because FFP outputs data at different range points for each SD pair. The method used is a simple, linear interpolation between neighboring (range-wise) data from FFP. This proved to be problematic because the range

increment chosen by FFP, typically, is more than one wavelength. Thus, a linear interpolation between such points was essentially meaningless. Even the crudest approximation would require point spacing of at least 4 points/wavelength. It was decided that approximately 10 points/wavelength would give adequate information to INTERP, so the interpolated field would closely resemble the original field.

The simplest approach to reducing the range increment was to insert a statement in the portion of FFP that determines the increment. The effect of the statement would be to divide the increment by a predetermined number. It was discovered that division of the range increment by an arbitrary number caused moderately erroneous output (between 0- and 1-dB difference in sound pressure levels). It was later found that the divisor had to be a power of 2 and the number of points had to be increased by the same power of 2 to achieve accurate results. The default number of points used by FFP is 1,024, and the maximum reasonable number to use is 16,384, which gives a maximum range divisor of 16. For a 170-Hz frequency, this provides a range increment of about one ninth of a wavelength, under typical atmospheric conditions. Similar results hold at other frequencies, and this range increment seems adequate for most purposes.

The addition of XTRASRC to AMPP required some additional modifications, including some new variables within FFP. Some of the variables control the sort of output AMPP produces. The *ampinput* file contains a list of some of the variables (and their values) used by AMPP. The *ampinput* file is read by AMPP (specifically, by the subroutine INPUT) to assign values to the variables. Three variables were added to this file to support the addition of XTRASRC: RINTO, RDELTA, and RLAST. The variables determine the grid of points at which the sound fields will be interpolated. As the names suggest, RINTO is the first range point at which XTRASRC will interpolate, RDELTA is the distance between the successive range points, and RLAST is the farthest range point at which XTRASRC will interpolate.

Five new variables are also amongst the arguments used in the call to FFP from the main portion of AMPP: (1) STYPE, tells FFP whether the source is a "true" source or a scatterer; (2) RPLUS, gives the range of the scatterer

(RPLUS equals zero for true sources); (3) STRENGTH, gives a multiplication factor for the sound pressure produced by a scatterer; (4) DTYPE, tells FFP whether the detector is a "true" detector or a scatterer; and (5) ISCAT, indexes the scatterers. The behavior of FFP is dependent on the values of STYPE and DTYPE. STYPE and DTYPE are integer quantities and use the following convention: If the object (source or detector) is true, the value is zero; if the object is a scatterer, the value is 1. Thus, FFP has four possible scenarios: (1) If both values are zero (true), FFP computes the field and sends it to XTRASRC, which interpolates it, saves it, and sums it with any fields it has saved. (2) If STYPE is zero and DTYPE is 1, FFP computes the field but only saves the value at RPLUS. XTRASRC is not called. The saved values are summed within FFP to determine the combined strength of the fields at each scatterer. (3) If STYPE is 1 and DTYPE is zero, FFP computes the field and sends it to XTRASRC, which interpolates it, saves it, and inserts a value of zero for the pressure at range points less than RPLUS. The result is summed with any fields saved by XTRASRC. If STYPE and DTYPE are 1, FFP is not called; no calculation is performed.

Prior to April 1993, a scatterer was treated as a source and detector by AMPP. The data regarding the location of the scatterers were merged with the source and detector data in the subroutine INPUT. A flag was set so FFP would not be called if a source was also a detector. The procedure was modified and separated from INPUT to form a new subroutine, MERGE, to streamline the operation and output of AMPP. Figure 1 is an updated block diagram for AMPP.

AMPP deals with scatterers in the following manner. First, the main portion of AMPP loops through the true sources with the scatterer locations used in place of detector locations. The output is discarded, except for the pressure caused by each source at each scatterer location. The pressures are summed at each scatterer location to determine the excitance at each scatterer. Next, the subroutine MERGE is called, which merges the scatterer data with the true source data. AMPP loops through both types of sources using the actual detector locations. FFP uses a standard excitance of 1 W/m^2, 1 m from the source. Thus, the computed pressure field must be multiplied by the excitance when FFP is called with a scatterer. Two other variables, STRENGTH and

PHASE, also multiply the pressure field of each scatterer. STRENGTH represents the scattering amplitude of the scatterer and is specified in the input file *ampscatt*. PHASE (also available for true sources) is the complex exponential of jϕ, where ϕ represents the phase angle relative to the first true source. The phase angle is specified in degrees in the file *ampscatt* (or *ampsourc* for true sources).

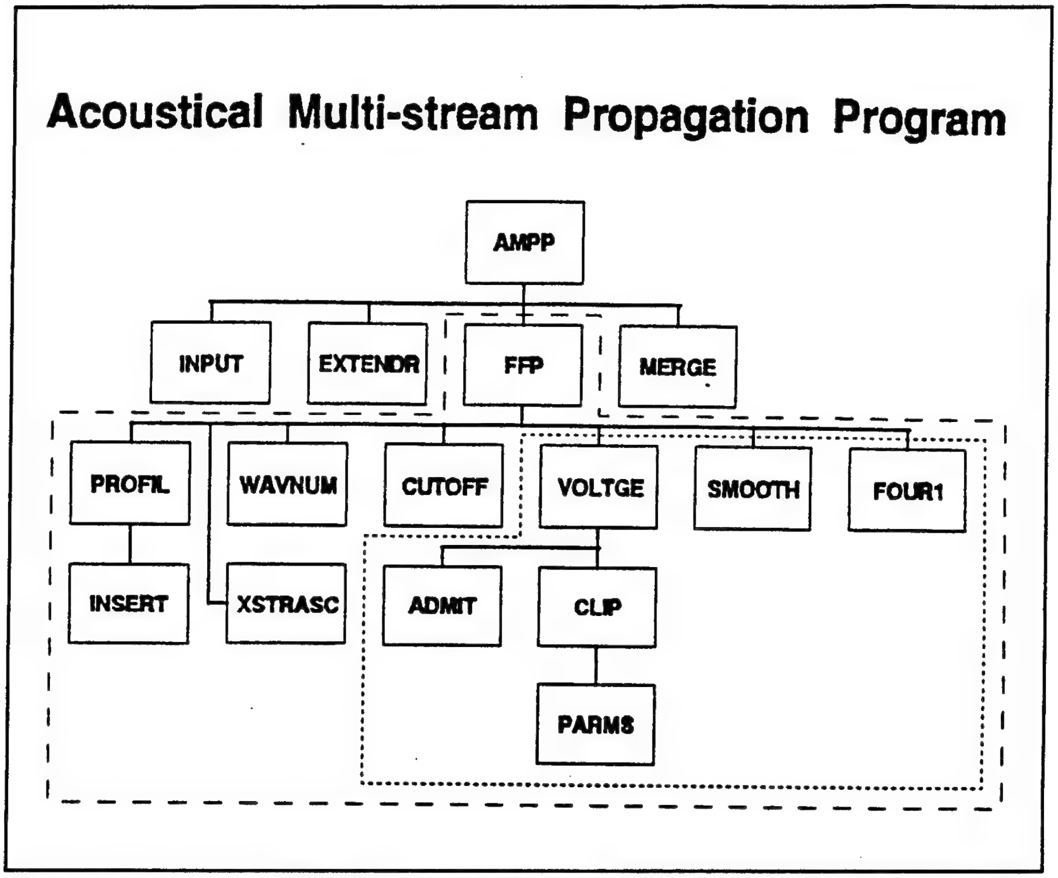

Figure 1. Updated AMPP block diagram.

3. Use of AMPP to Model Anisotropic Scatterers

This section describes the use of AMPP to model anisotropic sources and scatterers. In general, five separate programs are required to produce a graphic display of the field from such sources/scatterers (or, actually, any field):

1. MET reads in meteorological data in ARL standard format and converts it to a form readable by the next program, MENU3.

2. MENU3 converts the output from MET to the form required for AMPP.

3. AMPP calculates the field.

4. AMP2MATH converts AMPP output to a form suitable for input to MATHEMATICA.

5. MATHEMATICA, a commercially available software package, among other capabilities, produces contour plots.

More specific information on the use of these programs can be found in a technical report by Auvermann, Reynolds, and Brown (1995). If a special type of atmospheric condition (uniform atmosphere) is required, the first two steps are omitted, and the input file (*amplayer*) can be prepared using a text-editor.

In general, it is difficult to see the effects of scatterers when all the summed fields are displayed in the output because each scattered field has only a fraction of the intensity of the source field at any point. Thus, it is sometimes useful to display only the scattered field in the output, which can be done by specifying FOUT = 1 in the file, *ampinput* (choose FOUT = 0 for normal output — all fields displayed).

Figure 2 depicts a scenario of a single source and dipole scatterer in a uniform atmosphere with no boundary reflections. The frequency is 170 Hz and the sound speed is 340 m/s, giving an acoustic wavelength of 2 m. A dipole scatterer such as this can be simulated by placing two scatterers one-half wavelength apart, so the line joining them is perpendicular to the line

that connects the source to the midpoint of the dipole. In this case, the source was positioned at 25-m height (and zero range), and the scatterers were positioned at 99.7-m range and 100.4-m height and 100.3-m range and 99.6-m height. Only the scattered field is displayed here.

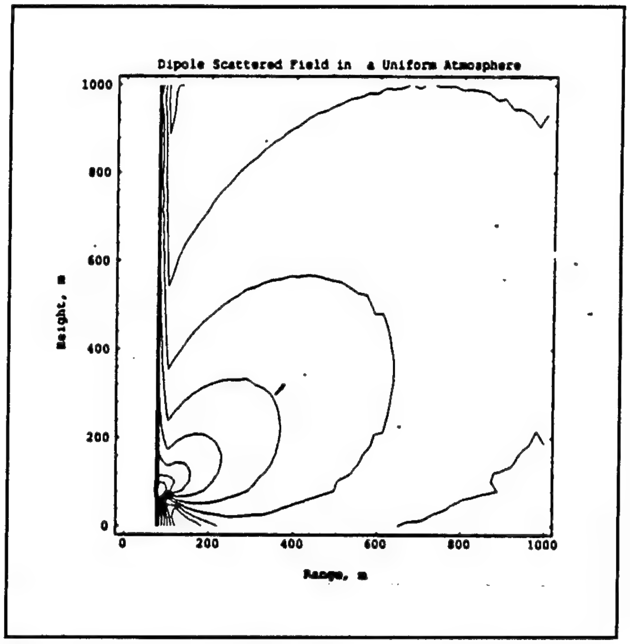

Figure 2. Dipole scattered field in a uniform atmosphere.

The general case of a nonuniform atmosphere often renders simple scenarios (figure 2) that are almost unrecognizable. For example, figure 3 represents the same source/scatterer configuration as figure 2; however, an upward refracting atmosphere has been used, and ground reflection has been included. Once again, only the scattered field is displayed.

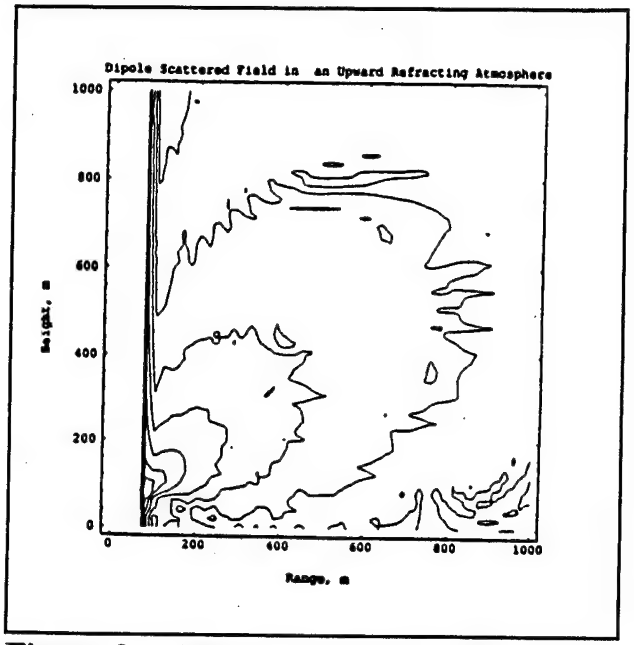

Figure 3. Dipole scattered field in an upward refracting atmosphere.

Also of interest in an upward refracting atmosphere is the presence of a shadow zone. Figures 4 and 5 represent similar scenarios, each with one source (at 10.02-m height) in an upward refracting atmosphere (with -0.00367 s^{-1} sound speed gradient); however, figure 5 includes a scatterer (with STRENGTH = 100) positioned near the boundary of the shadow zone (4000-m range and 100-m height). The contribution from the scatterer is clearly evident in such a case, even with all fields summed (and displayed).

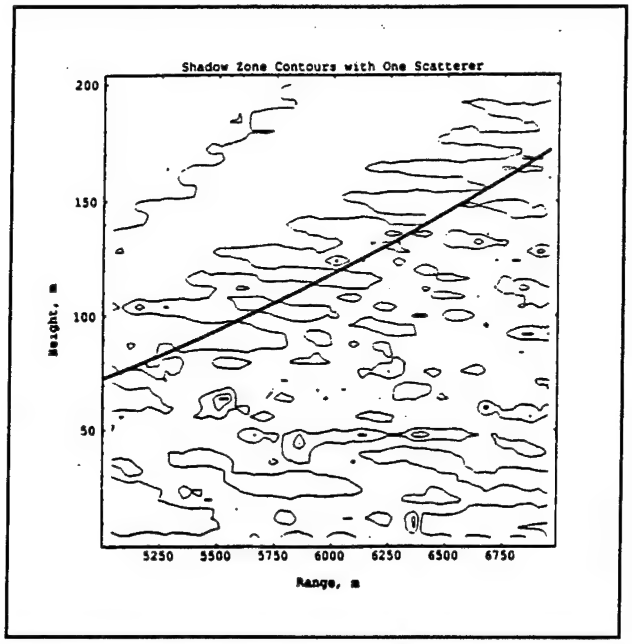

Figure 4. Sound field from a single source in an upward refracting atmosphere.

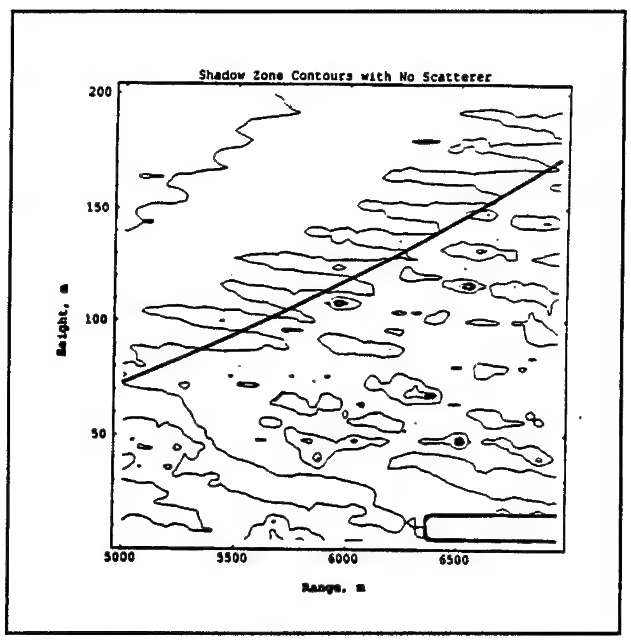

Figure 5. Sound field from a single source in an upward refracting atmosphere with the scatterer field added.

4. Conclusion

This paper concludes with a summary of the description of AMPP, and some final remarks concerning the limitations of AMPP.

AMPP is a computer program developed by ARL to compute sound pressure levels from multiple sources, at multiple detector heights, in a stratified atmosphere, and over a flat earth. The ground and the boundaries between atmospheric layers are modeled as impedance surfaces. AMPP is based on the FFP, to which it makes a call for each SD pair. Scattering by atmospheric turbules is taken into account by representing the turbules, or scatterers, as sources with nonzero range. Although FFP calculates sound pressure levels only for isotropic sources, AMPP is able to model anisotropic sources by coherently summing the output of several, appropriately positioned and phased sources and scatterers. Graphical output in this report displayed a dipole scatterer in uniform and upward refracting atmospheres. The phenomenon of scattering into an acoustic shadow zone is displayed.

The fundamental limitation of AMPP is that it cannot be converted to a three-dimensional model, which limits its usefulness in real-life situations. Also worth consideration is the amount of computing resources required by AMPP. It was necessary to increase the number of points used by FFP to 16,384 (from 1,024) to accommodate the coherent summation subroutine, which lead to approximately a four-fold increase in the run time of AMPP. Each dipole plot in section 3 took approximately 2 h to run. Thus, for a significant amount of scatterers (100) one could expect to wait 2 to 3 days for the output (times for a Sun SPARCstation IPC). Numbers approaching an ensemble of scatterers are completely unadvisable.

Additional user-oriented information about AMPP can be found in appendices A and B.

References

Auvermann, H. J., and G. H. Goedecke, "Acoustical Scattering From Atmospheric Turbulence," In *Proceedings 1992 Battlefield Atmospherics Conference*, U.S. Army Research Laboratory, White Sands Missile Range, NM, December 1992.

Auvermann, H. J., R. L. Reynolds, and D. M. Brown, *Development of a Multistream Acoustic Propagation Model Including Scattering by Turbulence*, ARL-TR-528, U.S. Army Research Laboratory, White Sands Missile Range, NM, 1995.

Raspet, R., S. W. Lee, E. Kuester, D. C. Chang, W. F. Richards, R. Gilbert, and N. Bong, "A Fast-Field Program for Sound Propagation in a Layered Atmosphere Above an Impedance Ground," *Journal of the Acoustic Society of America*, **77**, 2, February 1985.

Acronyms and Abbreviations

AMPP	Acoustic Multistream Propagation Program
ARL	Army Research Laboratory
FFP	Fast Field Program
SD	source detector

Appendix A

Error Checking Techniques for the Acoustic Multistream Propagation Program

The simple scenario of a uniform atmosphere with no ground reflection provides a useful set-up for determining the quality of results produced by the Acoustic Multistream Propagation Program (AMPP). Such a scenario has simple theoretical formulae to calculate the correct sound pressure levels with or without molecular absorption. For a single source and constant molecular absorption δ, the formula is

$$p=\frac{p_0}{r}e^{-\delta r}. \tag{A-1}$$

This expression gives the sound pressure at a distance of r meters from the source. The exponential term drops out entirely when there is no molecular absorption. The sound pressure 1 m from the source, p_0, is set to one by FFP.

In a uniform atmosphere with no ground reflection, the field produced by a single source is symmetric about the source. Also, the field produced by a dipole scatterer has a simple, recognizable geometry that provides a convenient method of checking AMPP for errors. If the field produced by AMPP does not have the expected geometry, one or more input quantities have been chosen incorrectly (the AMPP code itself has been debugged). In fact, the presence of anomalous asymmetries in a dipole pattern led to the development of a decision making tool for the choice of a certain input parameter — namely, the extra attenuation.

To surmount the difficulty in numerically integrating over branch points and poles, FFP includes a small loss in the atmosphere, known as the extra attenuation, which is corrected for in an approximate manner after the integration has been performed. Franke and Swenson* noted that "the proper choice of this "artificial" attenuation is *essential* if meaningful results are to be

*Franke, S. J., and G. W. Swenson, Jr., "A Brief Tutorial on the Fast Field Program (FFP) as Applied to Sound Propagation in the Air," *Applied Acoustics*, **27**, 1989.

obtained from the code." They do not, however, provide an example of a reasonable value to use, nor do they give any guidance on how to choose a proper value. The variable is given the name EXTRA in AMPP.

Figures A-1 and A-2 show plots of the formula in equation (A-1), overlaid with Fast-Field Program (FFP) output, for two values of extra attenuation. The figures show the sort of problematic output that can occur, when the value is too high or too low. For a good value (such as 0.001), the deviation of the FFP output from the reference curve is so slight the plots are virtually indistinguishable.

It seems reasonable to assume that input parameters that provide good results in uniform atmospheres should be acceptable for nonuniform atmospheres. Unfortunately, this is not easily verified, because of the complexity of the expected results in such a scenario.

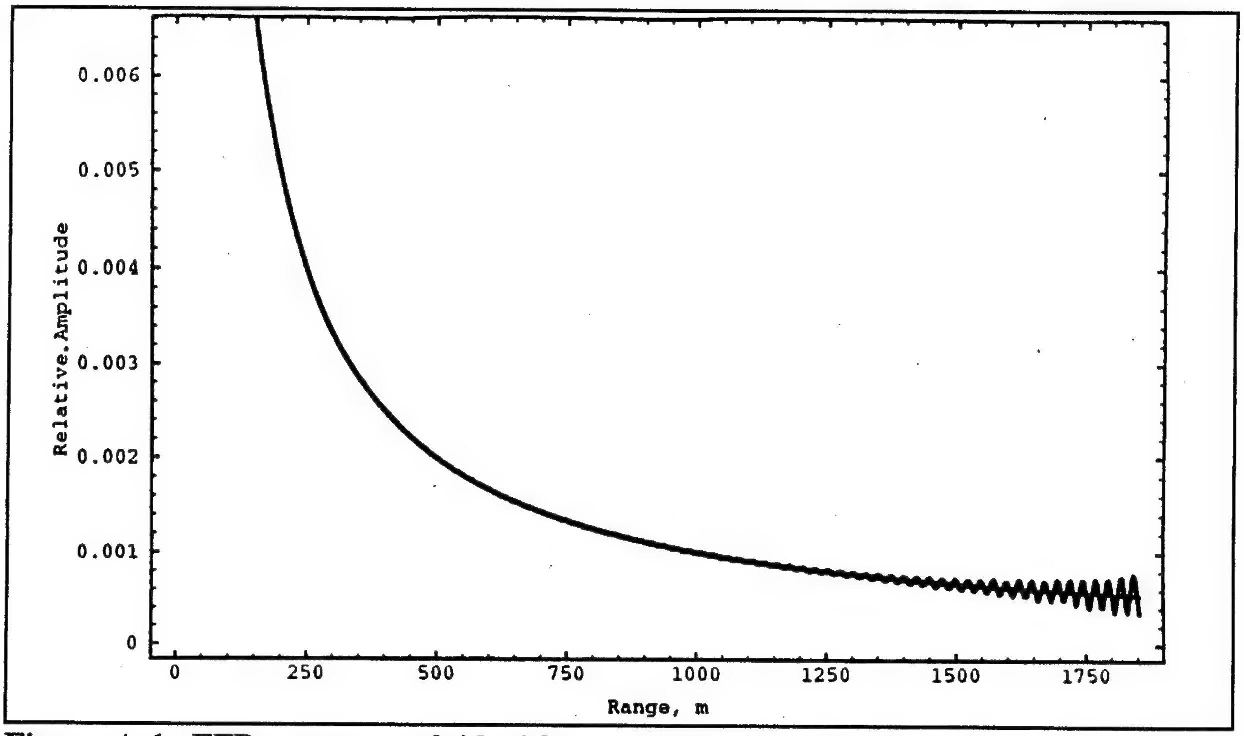

Figure A-1. FFP output overlaid with exact solution, with extra attenuation = 0.0045 (too high).

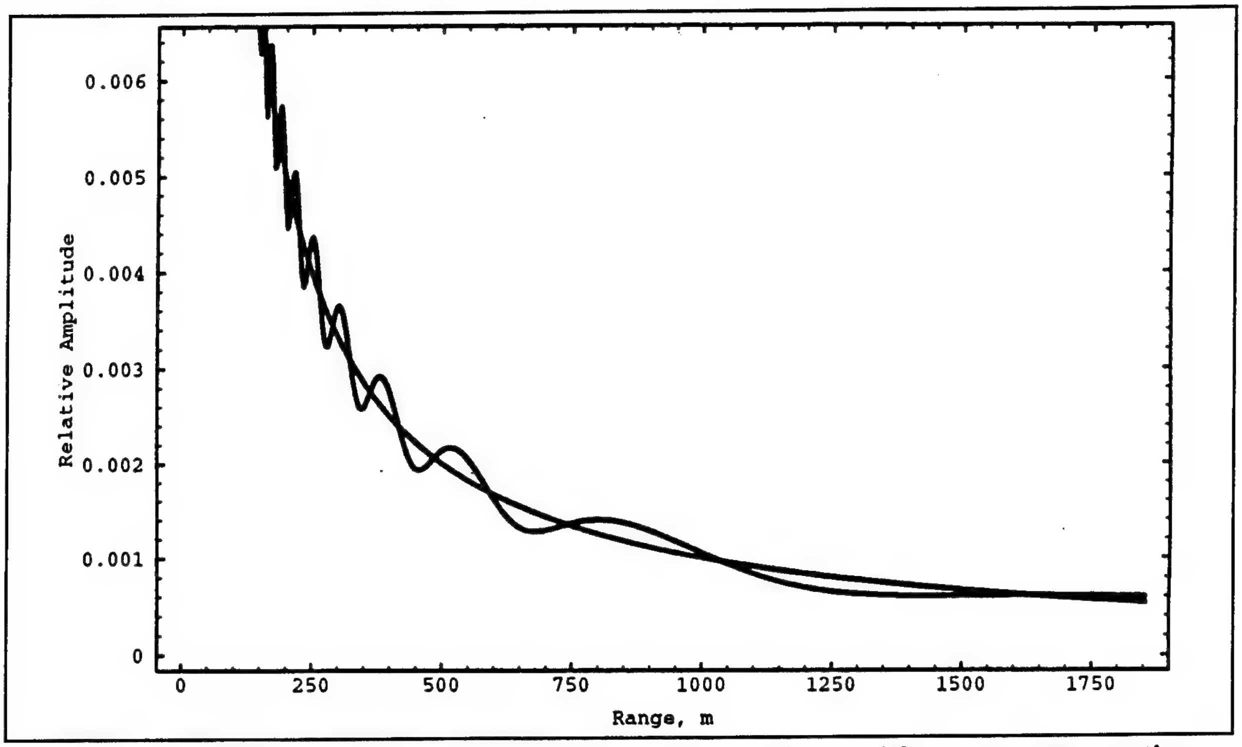

Figure A-2. FFP output overlaid with exact solution, with extra attenuation = 0.00028 (too low).

Appendix B

Rules of Thumb for the Use of the Acoustic Multistream Propagation Program

For the successful use of the Acoustic Multistream Propagation Program (AMPP), the main consideration is the judicious selection of input quantities. As seen in appendix A, a haphazard choice of extra attenuation can lead to questionable results. The various input quantities for AMPP can be divided into three basic types:

- atmospheric profile contained in the file *amplayer*

- source, scatterer, and detector data, contained in the files *ampsourc*, *ampscatt*, and *ampdetec*, respectively

- miscellaneous quantities contained in the file *ampinput*

Of all the quantities in *ampinput*, EXTRA is the most sensitive. The procedure for determining a good value for EXTRA was presented in appendix A. The choice of EKZMAX has an effect on the extent of the numerical integration in the wavenumber domain. As long as this value is sufficiently high (about 10^8 works well), the particular choice is not important. For the current version of AMPP, the value of POINTS should be kept at 16,384, so that errors do not arise from the interpolation routine (section 2). Note that choosing OUTPUT equal to zero (instead of the default of -1) is equivalent to running the old version of AMPP (without interpolation or coherent summation), so 1,024 would be an acceptable value for POINTS in that case.

It is important that the files, *ampsourc*, *ampscatt*, and *ampdetec*, are structured appropriately. The basic structure of *ampsourc* and *ampscatt* is as follows:

```
1
0.0000 1.0000 2.0005 180.0
```

The first line represents the number of sources/scatterers. If a 5 is in the first line, five more lines of this file will be read in by AMPP. The fields on each line after the first follow the following order: R (horizontal range in meters), Y (source/scatterer amplitude), Z (vertical distance in meters), and P (phase angle in degrees relative to the first source). The format for *ampdetec* is basically the same, except there are only three fields on each line after the first.

These fields contain R (horizontal range in meters), Y (not used), and Z (vertical distance in meters). The following checklist summarizes the rules for choosing the values contained in the files:

- There must be at least one source and one detector.

- If n is the number on the first line, there must be at least n+1 lines in the file, or random data will be entered for the missing lines.

- All sources must be positioned at zero range.

- All scatterers should have a range of at least 10 m.

- All detectors should have a range of at least 100 m.

- No two detectors should have the same height.

- No detector should be placed at the height of an atmospheric layer boundary.

- No detector should be placed at ground level (zero height).

- No detector should be placed higher than the top atmospheric layer boundary.

- The value on the first line in each file is read as an integer. Each value on subsequent lines is read as a real number.

- All values in the files should be non-negative.

The *amplayer* file contains the atmospheric profile. The structure of *amplayer* has been documented in a technical report by Auvermann, Reynolds, and Brown.* One peculiarity of *amplayer* is that it requires a line of null data as its last line. The program does not use this data, but crashes without it! Typically, the more complicated the atmosphere, the more lines are required in *amplayer*. It is not necessary that successive layer boundaries be a uniform distance apart. Thus, the least uniform regions of the atmosphere should contain most of the layer boundaries. Also, boundaries between uniform and nonuniform sections of the atmosphere should have several layers of transitional data.

*Auvermann, H. J., R. L. Reynolds, and D. M. Brown, *Development of a Multistream Acoustic Propagation Model Including Scattering by Turbulence*, ARL-TR-528, U.S. Army Research Laboratory, White Sands Missile Range, NM, 1995.

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